Stream water quality and its influencing factor in lower order streams in upriver sections of Ashihe River

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Abstract: For understanding the reasons that caused the degradation of water quality in lower order streams, systematic sampling was conducted at different spatial locations along the low order streams (1st-5th) of Ashihe River continuum in Maoershan Experimental Forest of Northeast Forestry University, Shangzhi City, Heilongjiang Province, China. The indexes of stream water quality, i.e., the pH, dissolved oxygen(DO), turbidity, temperature, PO_4^{3-}-P, NO_3^--N and NH_4^+-N concentrations, total dissolved inorganic nitrogen (TDIN-N, including concentrations of NO_3^--N and NH_4^+-N), and total phosphorus (inorganic and organic phosphorous, TP) were measured and analyzed. The stream order, related environmental settings and land-use type were recorded for each sampling location. The indexes of stream water quality at different locations with different stream orders and land use types were compared by ANOVA analysis. The indexes of stream water quality at different sampling locations were analyzed by Hierarchical cluster analysis. Result showed that water quality had significant difference in different stream orders and land use types; some locations with different stream features (stream order and land use type) were grouped into same clusters, indicating that random disturbances produced the variations in water quality, which made the spatial variances of stream water quality inconsistent with the general rules.

Keywords: Stream water quality; Land-use; Stream order; Hierarchical cluster analysis
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Introduction

Almost all of the rivers and lakes in the world are suffering from pollution of N, P and sediments caused by soil and water erosion, pollutants emission and excessive fertilization (Carpenter *et al.* 1998; Howarth *et al.* 2000). Non-point pollution was the main source of the water body pollution, e.g., 60% of water pollution in the US belongs to non-point pollution (US EPA 1995). Of the 270 streams assessed in Danmark, 94% N loading and 52% P loading were from non-point pollution (Kronvangl *et al.* 1996). In China, water suffered from even more severe pollution, 80% of the 532 rivers surveyed were influenced to some degrees by N pollution, therein, N in the runoff from cropland accounted for 51% (Ma *et al.* 2000). In the early 1970s', efforts have been made to improve water quality in China, but few results have been achieved since non-point source pollution control has not been given enough consideration (Yang *et al.* 1999).

In the developed countries, researches on non-point pollution control have been done for decades, and the techniques for non-point pollution control have been put into practical use (Yin *et al.* 2002). Unfortunately, Works on water quality control have been lagged behind in China. Because China is featured with the largest population, the heaviest land-use disturbances, and complex natural conditions, the surface water pollution in China is worse than that in developed countries.

Therefore, much work needs to be done in the management and control of non-point pollution in China (He 1998). Identification of the key causes of non-point pollution is the first step for water pollution control. Surveying of stream water quality at different locations and analyzing of the environment factor can provide information of water body pollution and its sources (Simeonov *et al.* 1999). One of the common methods for water quality survey is to sample intensively at locations along streams with different features, which involves sampling from a large number of sites in the whole watershed over a short period of time (Eyre *et al.* 1999). The advantage of this approach is to provide detailed information from across the watershed for assessing the influence of land-use patterns, instream nutrient processes, point source input, and stream order on water quality (Grayson *et al.* 1997). Walling and Wedd (1975) conducted the first study on water quality by using this approach, and measured the electrical conductivity of stream water. Their results illustrated that the primary and secondary contributors to water quality were geology and land-use patterns, respectively. Turner *et al.* (1996a, b) also employed this approach to demonstrate the influence of geology and land-use patterns on water quality at different locations by investigating stream water turbidity and conductivity. However, this method has not been widely utilized in study on stream water quality in our China (Mou *et al.* 2004).

Hierarchical cluster analysis is a multivariate statistic approach dealing with classification issues. This classification method is more reasonable and reliable to analyze the factors that impacts stream water quality (Reghunath *et al.* 2002; Wunderlin 2001).

In order to compare the water quality in different order streams and under different land-use patterns, we surveyed the indexes of water quality from 1st to 5th order streams along the Ashihe River continuum at Maoershan Experimental Forest, Northeast Forestry University, Heilongjiang Province, China. The water quality in streams with different orders, and under land-use patterns was compared. The sampling locations were grouped by Cluster analysis on the basis of water quality and

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related environmental settings, and the further analyses were made to illustrate the reasons that resulted in the difference of water quality at locations in different groups. The information drawn out from this study would be helpful for us to understand the general rules of controlling the stream water quality and provide the basis for making policy on land-use patterns.

Materials and methods

Study sites

The study sites was along the Ashihe River continuum at Maoershan Experimental Forest, Northeast Forestry University, Heilongjiang Province, China (N45°23'–45°26', E127°26'–127°39') with a total drainage area of 26 000 hm^{-2}. This area was featured with typically terrestrial monsoon climate, and it is cold and dry in winter, hot and humid in summer. Mean annual temperature is 2.8 °C. The annual mean precipitation is 723.8 mm, distributing unevenly all year round, with 54% concentrating in July and August, and the annual evaporation is 1 094 mm. The soil is Dark-brown Forest Soil under natural forest vegetation, with high organic matter content, characterized by well drainage and aeration properties. The forest coverage was 70% and the major vegetation of secondary growth forest was dominated by broadleaved tree species.

Collection and analysis of stream water

The 1st-5th order streams were determined by aerial photos (1:15000) (2003) and hydrological map (1:5000) of the Maoershan Experimental Forest. Starting from with the 1st order stream, stream water samples were collected every 500 (±50) m along the Ashihe River. Extra samples were taken at 50 m downstream from the joint points of two tributaries. For the 4th and 5th order streams, water samples were taken every 1000(±50) m to the last location at 1 km downstream from Maoershan Town (Fig 1). Totally 65 sample sites were chosen, water samples were taken and the environmental features of each sampling location were recorded.

At each sample location, turbidity, dissolved oxygen (DO) and temperature were measured *in situ* by using HI93703-11 portable nephelometer (Hanna Instruments, Italia), HI9143 portable DO meter and thermometer (accessory of DO meter, Hanna Instruments, Italia), respectively. The water samples were collected by using 500-mL plastic sampling bottles washed with 5% HCl solution in advance and washed 3 times with stream water at each sampling location. All the sampling work was conducted within 3 days from 26 to 29 July, 2004.

The water samples were stored at 4℃ in coolers and delivered to laboratory for analysis. The concentration of NH_4^+-N, NO_3^--N, PO_4^{3+}-P, and TP were determined by Nessler's reagent colorimetric method (GB 7479-87), spectrophotometric method with phenol disulfonic acid (GB 7480-87)and annonium molybdlate spectrophotometric method (GB 11893-89), respectively. The pH value was measured by portable pH meter (pH213, Hanna Instruments, Italia). All the measurement was repeated for three times; if wild data emerged, extra measurement was made, and the wild data were eliminated from the data set.

Data analysis

SPSS11.5 software was used for data analysis. ANOVE test was used to compare water quality indexes in streams with different orders, and land-use patterns. Meanwhile, hierarchical cluster analysis was applied to group sampling locations on the basis of water quality. The data was processed (after data scaling by z-transformation) by the Ward's method of linkage with squared Euclidean distance as measure of similarity (Simeonov *et al.* 2003). The independence of the data was tested by the spearmen correlation analysis ($p<0.05$). If the data were not independent, two sample locations were pooled until the interrelation disappeared.

Results

Water quality in different order streams

Water quality indexes in lower order streams (1st through 3rd) had no significant difference, except for concentration of PO_4^{3-}-P and TP and temperature, which were significantly greater in the 3rd order streams (Table 1). Comparison of water quality indexes between lower order streams (1st through 3rd) and higher order streams (4th and 5th) showed that the concentration of NO_3^-N and TDIN in 4th order streams, and DO, turbidity and temperature of 5th order streams were significantly greater than those of the lower order streams. The concentration of PO_4^{3-}-P and TP in the 3rd order streams were significantly higher than those of higher order streams.

Water quality in streams with different adjacent land-use patterns

The concentrations of NO_3^--N, TDIN and temperature in the streams within forest area were significantly lower than those in the streams in cropland area and in streams in adjacent to townships. DO was lower and concentrations of PO_4^{3-}-P in forested streams was higher than those of the town streams. Significant difference was found only in turbidity between cropland streams and the town area streams (Table 2).

Cluster analysis of stream water quality indexes in different spatial sampling locations

The 65 sampling locations were grouped into four clusters (Table 3). Most locations in cluster 1 were from forested and low order (1st to 2nd) streams with relatively well developed forested riparian zones except for location 40, 41 and 43, 46 which were from 3rd order streams and 1st order streams in cropland, respectively. Locations 40, 41 were from streams in adjacent to cropland to one side and forest land to the other, with relatively complete riparian vegetations. Location 43 and 46 were from in the 1st order streams in cropland, with slightly disturbed riparian vegetation. The sampling locations fell into cluster 2 were mainly from the 3rd order streams with all riparian vegetation zone disturbed and dominant adjacent land-use patterns of forests, with the exception of location 45, 53, 54, 55, 57. These locations were from streams in cropland area, 4th order streams (45, 53, 55), the 1st order stream (54), and the 5th order stream (57). Most of the locations in cluster 3 were from streams in cropland with the dominant crop species of corn, soybean and rice, the 4th stream order and heavily disturbed riparian zone. Location 51 was from the cropland, 1st order stream with bared riparian zone. The sampling locations in cluster 4 situated predominately in the 5th order stream, with major land-use patterns of cropland, villages and town spotted close by; and the riparian vegetation was heavily destroyed or even complete gone.

Table 1. Stream water quality indexes of different order streams in the Ashihe River watershed by one-way ANOVA and multiple comparison

Items		NO_3^- ($mg \cdot L^{-1}$)	NH_4^+ ($mg \cdot L^{-1}$)	TDIN ($mg \cdot L^{-1}$)	PO_4^{3-} ($mg \cdot L^{-1}$)	TP ($mg \cdot L^{-1}$)	pH	DO ($mg \cdot L^{-1}$)	Turbidity (NTU)	Temperature (℃)
MS		1.001	0.002	0.943	0.002	0.006	0.475	8.252	33.149	68.240
F-value		9.182	0.676	8.274	9.506	3.028	1.648	5.461	15.354	14.466
p-value		<0.0001	0.611	<0.0001	<0.0001	0.024	0.174	0.001	<0.0001	<0.0001
	1	0.6999b	0.3493a	1.0492b	0.0360b	0.0533b	6.856bc	8.3478a	2.7678b	15.411c
	2	0.6962b	0.3618a	1.0581b	0.0289b	0.0441b	7.063ac	8.9667a	2.9625bc	16.100c
Stream order	3	0.5018b	0.3764a	0.8782b	0.0535a	0.0929a	7.037ac	8.5106a	3.6488b	17.776b
	4	1.3467a	0.3488a	1.6955a	0.0277b	0.0475b	6.741bc	9.1700a	2.3125c	18.550b
	5	0.6583b	0.3698a	1.0281b	0.0317b	0.0518b	7.303a	10.4610b	6.7930a	21.510a

Notes: Data with different letters of a, b, c indicating significantly different at $p<0.05$ lever, by LSD post hoc comparison. Same is within the following tables.

Table 2. Stream water quality indexes between streams under different land-use patterns within Ashihe River watershed by one-way ANOVA and multiple comparison

Items	NO_3^- ($mg \cdot L^{-1}$)	NH_4^+ ($mg \cdot L^{-1}$)	TDIN ($mg \cdot L^{-1}$)	PO_4^{3-} ($mg \cdot L^{-1}$)	TP ($mg \cdot L^{-1}$)	pH	DO ($mg \cdot L^{-1}$)	Turbidity (NTU)	Temperature (℃)
MS	0.890	0.002	0.851	0.001	0.003	0.029	7.199	16.810	108.262
F-value	6.299	0.617	5.924	2.371	1.268	0.093	4.084	4.561	19.773
p-value	0.003	0.543	0.004	0.102	0.289	0.911	0.022	0.014	<0.0001
Forest	0.5948a	0.3623a	0.9771a	0.0405a	0.0568a	7.019a	8.5850a	3.1568a	15.968a
Cropland	0.8256b	0.3688a	1.1943b	0.0362ab	0.0748a	6.953a	9.1858ab	3.7200a	19.279b
Township	1.0688b	0.3428a	1.4117b	0.0275b	0.0484a	6.988a	9.9688b	5.3988b	20.400b

Table 3. Results of the land-use patterns classification of all sampling locations by the cluster analysis

Cluster	Number of the sampling locations	The stream order, riparian zone character, land-use patterns of the main sampling locations
1	1, 2, 3, 4, 5, 6, 7, 8, 10, 23, 24, 25, 26, 27, 28, 29, 30, 31,32, 33, 34, 35, 36, 37, 38, 40 41, 43, 46	1st, 2nd order, intact riparian zone, forest
2	9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 39, 42, 44, 45, 53, 54, 55, 57	3rd order, riparian zone destroyed slightly, forest and cropland
3	48, 49, 50, 51, 52	4th order, riparian zone destroyed heavily, cropland
4	47, 56, 58, 59, 60, 61, 62, 63, 64 , 65	5th order, riparian zone destroyed heavily, town

Water quality indexes between clusters had significant difference except for concentration of NH_4^+-N (Table 4). The concentrations of PO_4^{3-}P and TP, turbidity, and temperature of cluster 1 were significantly lower than those of cluster 2, NO_3^--N, TDIN and temperature were significantly lower than those of cluster 3, and pH, DO, turbidity and temperature were lower than those of cluster 4. In cluster 2, the concentrations of PO_4^{3+}-P and TP were significantly higher than those of the cluster 3 and 4, turbidity significantly higher than those of the cluster 3, the concentration of NO_3^--N, TDIN significantly lower than those of the cluster 3, pH, temperature and turbidity were significantly lower than those of the cluster 4. The concentrations of NO_3^--N, TDIN in cluster 3 was higher, and pH, DO, turbidity and temperature lower than in cluster 4 (Table 4).

Table 4. Stream water quality indexes between locations in different clusters within the research section in the Ashihe River watershed by one-way ANOVA and multiple

Items	NO_3^- ($mg \cdot L^{-1}$)	NH_4^+ ($mg \cdot L^{-1}$)	TDIN ($mg \cdot L^{-1}$)	PO_4^{3-} ($mg \cdot L^{-1}$)	TP ($mg \cdot L^{-1}$)	pH value	DO ($mg \cdot L^{-1}$)	Turbidity (NTU)	Temperature
MS	2.541	0.001	2.608	0.002	0.008	0.825	11.868	46.440	97.715
F-value	53.043	0.352	57.086	15.448	3.982	3.015	8.220	23.066	22.677
p-value	<0.0001	0.788	<0.0001	<0.0001	0.012	0.037	<0.0001	<0.0001	<0.0001
1	0.6441b	0.3559a	0.9972b	0.0313b	0.0466a	7.010b	8.595b	2.733c	15.386a
2	0.5772b	0.3611a	0.9383b	0.0526a	0.0884b	6.844b	8.542b	3.801b	18.510b
3	1.9015a	0.3772a	2.2787a	0.0258b	0.0468a	6.740b	9.106b	1.560c	17.780b
4	0.6616b	0.3724a	1.0341b	0.0304b	0.0525b	7.403a	10.634a	6.696a	21.260c

Notes: the number 1, 2, 3, 4 in the left most column stand for the four clusters.

Discussion

The stream order not only reflects the location of stream in the watershed but also closely related to water quality (William 2001). Different ecological processes happened in streams of different orders, which contributed to the differences of water quality (Nainan *et al.* 1987). Usually, low order streams subjected to relatively light disturbance, with the main land-use of forests and intact riparian vegetations, which made the stream a light- and nutrient-limiting ecosystem (Tate 1990; Wold *et al.* 1999). Our data partially supported these general laws in that the concentrations of PO_4^{3-}-P, TP and temperature in the 1st and 2nd order streams were lower than those in the 3rd order streams, the concentrations of NO_3^--N, TDIN, and temperature of lower order streams (1st through 3rd) were significant lower than those in 4th order stream, and temperature, turbidity were significantly lower than those in the 5th order stream (Table 1).

Some unusual results were also found in water quality indexes of different order streams. PO_4^{3-}-P and TP concentrations, turbidity of the 3rd order streams were significantly higher than those of the 4th and 5th order streams, and DO and temperature were significantly lower than those of the 5th order streams (Table 1). Usually, DO in lower order streams should be greater than that in the higher order ones due to the low temperature produced by shading of riparian trees and the less pollutants input to the lower order streams. Our data did not follow this general rule. The random disturbances from cow grazing and other human disturbances, and the fairly low discharge and velocity of flow in lower order streams might be responsible for the results. Heavy, frequent and random disturbances on streams of all orders, and relatively gentle slope are the main features of the watershed surveyed. Those results implied that adequate results could not be achieved by relying on only the stream order to explain the water quality.

With the increasing of stream order, the land-use patterns changed in the following successive order: forest, cropland, villages and township, the frequency and intensity of human disturbance increased. Different land-use patterns produced different impacts on stream N, P nutrient (Jordan *et al.* 1997a, b; Wernick *et al.* 1998). Our data (Table 2) showed that NO_3^--N and TDIN concentration, temperature in the forested streams were significantly lower than those in the agricultural and the villages/town area streams. These could be attributed to the greater forest coverage and better functioning of the riparian forests. Some studies demonstrated that different land-use patterns, e.g., forest land, cropland, pasture, had different influences on the runoff and the nutrient concentrations in stream water. Forest was the land-use pattern with the least adverse impact (Herpe *et al.* 2000). Unfortunately, some of our data did not follow this general rule in that PO_4^{3+}-P concentration of streams in forest area was significantly higher than that in streams in inhabited area. These implied that the water quality of streams in forested area was not necessarily better than that of streams in the inhabited/agricultural area. The heavily random disturbances on stream riparian zones and the streams themselves in forested area could degrade the water quality in streams as well.

On the basis of the similarities of stream water quality indexes at each sampling location, the different locations were classified into 4 clusters. This made it more rational to relate water quality at each location to the environmental settings. Most of the water quality indexes at locations in each cluster were significantly different from those in other clusters (Table 3).

Locations in cluster 1 were predominantly from lower order streams (1st and 2nd) in forested area (Table 3). Usually, forest is often believed to be the land-use type that most efficiently reduces stream N, P loading (Phillips, 1989; Williams *et al.* 1997; Lebo *et al.* 1998); moreover, low order stream ecosystems are more efficient in retaining and transforming the nutrients and sediments. So the concentrations of the nutrients and sediments of forested low order streams are usually lower (Mulholland *et al.* 2001; Peterson *et al.* 2001). Our data partially agreed with these general rules. The PO_4^{3-}-P and TP concentration, turbidity, and temperature of cluster 1 were significantly lower than those of cluster 2. NO_3^--N and TDIN concentration and temperature of cluster 1 were significantly lower than those of cluster 3. Turbidity and temperature of cluster 1 were lower than those of cluster 4 (Table 4). Although the sampling locations of 40, 41, 43, and 46 were not from the forested 1st or 2nd order streams, they were grouped into cluster 1. The reason was that these sites had relatively intact riparian vegetations which are efficient at reducing the input of the nutrients and sediment of the surface and underground runoff to the streams (Cooper, 1993; Petenohn *et al.* 1984; Clausen *et al.* 2000).

The sampling locations fell in cluster 2 were mainly from 3rd order streams in forested area, with all riparian zone vegetation disturbed to some degree. The relatively higher forest coverage and riparian zone vegetation result in water quality in streams in cluster 2 better than that in cluster 3 and cluster 4, with the exception of PO_4^{3+}-P, TP and turbidity (Table 4). The probable reason for high concentration of PO_4^{3+}-P, TP and high turbidity in streams in cluster 2 might be due to serious soil erosion and the direct input of feces from cattle trampling within the streams and along the stream banks. Research has proved that the input of P to streams usually happens with the input of sediments (Carpenter *et al.*1998). The other locations in cluster 2, i.e., 45, 53, 54, 55, 57, were located in 3rd to 4th order streams, with adjacent high land of the cropland. Usually pollutant loading from the cropland is more than that from the forested land. The greater discharge of these streams (from *in situ* observation) in comparison to other locations in cluster 2 might contribute to the result. Dilution effect from greater discharge of these streams makes water quality of these locations similar to other locations in this cluster.

The land-use pattern for most locations in cluster 3 was mainly cropland. Intensive fertilization in the cropland and the serious disturbance of riparian zone usually produced higher input of TN, NH_4^+-N, NO_3^--N for stream water (Eyre *et al.* 1999). This was consistent with our result and the concentrations of NO_3^--N, TDIN of water at positions in cluster 3 were higher than others (Table 4). Location 48 and 52 were points located right downstream the villages, sewage discharge made water quality worse than that of other locations in cluster 2. The common feature of these two locations was that the streams had cropland to one side and forest land to the other side. This was the reason that the water quality at these two locations was better than that in cluster 4 even though two locations were located in populated areas.

The majority of locations in cluster 4 was located in the heavily populated area, the 5th order stream, with heavily disturbed highland and mostly open stream. TP, DO, pH, turbidity and temperature in stream water in cluster 4 were significantly greater than those in cluster 3 (Table 4). The increased disturbance intensity, industrial and household waster water discharge

and riparian removal should be partially responsible for these results. Location 47 should have been grouped into cluster 3 on the basis of its location (Fig. 1). The muddy rural road crossing upstream to the sampling location, and the pollution from the living trashes scattered in the riparian zone contributed to the unusual change of water quality at that location.

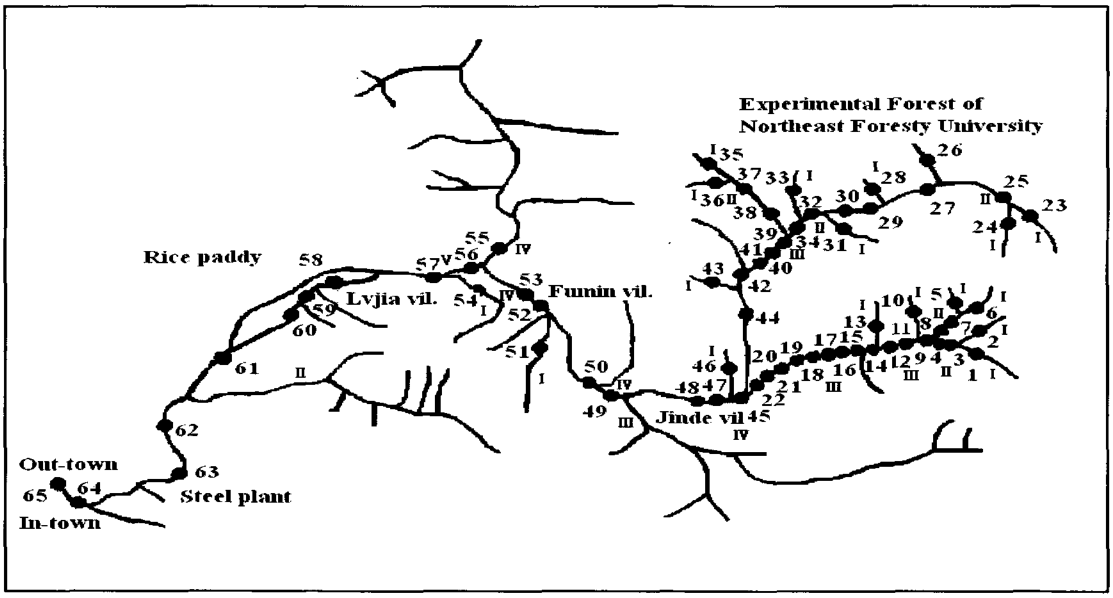

Fig. 1 Sampling sites along A'shihe River continuum

Notes: Roman numerals indicate stream order, and Aravic numerals indicate sampling sites.

In summary, the water quality of streams was influenced by many factors. Usually, stream order and land-use pattern played an important role in determining the stream water quality (Wil-liam 2001; Taraba *et al.* 1996). The water quality of lower order streams was better than that of higher order ones; and the water quality deteriorated with the increasing intensity of land-use, e.g., the stream water quality in forested area was better than that in cropland area and inhabited area (Hirose *et al.* 1981; Taraba *et al.* 1996). Within the watershed surveyed in this study, random dis-turbance produced some different influences on the water quality. The spatial variation of steam water quality did not always fol-low the general rule, disturbance on the riparian zone and non-point source input contributed much to the result. Not only the land-use pattern, riparian buffer zone maintenance, but also the random disturbance from local people should be taken into account to achieve the goal of water quality improvement within this kind of watershed.

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